

GARY A. PETERSON*Colorado State University
Fort Collins, Colorado***PAUL W. UNGER***USDA-ARS
Bushland, Texas***WILLIAM A. PAYNE***Texas A&M University
College Station, Texas***RANDY L. ANDERSON***USDA-ARS
Brookings, South Dakota***R. LOUIS BAUMHARDT***USDA-ARS
Bushland, Texas*

One section of this monograph described the diversity of dryland cropping systems of the world in terms of their environments and constraints. Common management themes which emerged from the various chapters include weather variability, crop diversity, tillage, erosion, and preservation of soil organic matter and nutrients. This chapter briefly summarizes these themes in relation to dryland agriculture and long-term sustainability.

WEATHER VARIABILITY

Dryland agriculture describes rainfed crop production in regions where limited precipitation generally results in plant water stress at some time during a crop's growing season. Precipitation is often erratic, both within growing seasons and between years. Successful crop production under such conditions depends on stored soil water as well as efficient use of precipitation that occurs during the crop's growing season. Because of high variability of precipitation during the growing season, water conservation, especially storage of precipitation in soil

during non-crop periods, is of extreme importance for successful crop production. Yet, even with good management, crops still sometimes fail because of inadequate water.

Weather variability is a dominant concern with dryland agriculture, as it relates to availability of water for use by crops, including its spatial and temporal distribution. Other weather factors that often affect dryland crop production include prolonged dry periods (droughts), snow capture and melt-water retention, hail and other destructive storms, temperature extremes, high solar radiation, and high winds.

Appropriate tillage and crop residue management practices, well-adapted crops, and fertility management are needed for capturing, conserving, and efficiently using water for dryland crop production. Another option to improve production under some conditions is water harvesting, where runoff water from non-cropped areas is concentrated and applied to adjacent cropland. It would be helpful if early drought warnings or drought forecasting could be further improved, thus allowing producers to change crop management tactics to minimize detrimental effects of a drought. The future impact of global climate change is uncertain, but it could exacerbate the problem of drought and high temperature in dryland regions.

CROP DIVERSITY

Diversification generally entails adding alternative crops to existing cropping systems, often to substitute for the fallow phase of a rotation. Fallow may consist of maintaining vegetation-free fields to increase soil water storage for use by the subsequent crop, or maintaining vegetated fields with a view toward restoring soil organic matter and soil fertility.

Crop diversification is key to cropping system design because of its benefits for pest and risk management. However, agroecological adaptation is a necessary condition for successful introduction of alternative crops. For viable economic production, adequate labor and other inputs must be sufficient and favorable market conditions must exist. The growing homogenization of the world into maize (*Zea mays* L.), rice (*Oryza sativa* L.), and wheat (*Triticum aestivum* L.)-based diets, even in developing countries, renders the incorporation of alternative crops more difficult. Indeed, most successful examples of crop diversification on a large scale involve the replacement of traditional crops with internationally-traded crops such as maize, wheat, and cotton (*Gossypium hirsutum* L.).

Sanders and Shapiro suggested that for some developing countries, introducing feed and forage crops for livestock consumption may increase crop diversity. In other situations, there may be "niche" crops that provide economic opportunities for a small number of farmers. Adding legumes and oilseeds to cereal-based systems is occurring in some regions, whereas transgenic crops may create opportunities for alternative products such as for energy or pharmaceuticals.

But, there are few alternative crops in most regions of the world, thus opportunities for diversification are rather limited. Thus, for both alternative and

traditional crops, there is a continued need for crop breeding efforts to improve cultivar adaptation to constraints such as heat, drought, low nutrient levels, and pests. Breeders need to develop cultivars that not only yield well in stressful environments, but also meet quality expectations of consumers and processors. Breeding efforts and cropping options likely will be improved by modern molecular tools. Globally, yield potential needs to be increased if dryland agriculture is to meet the challenge of achieving food security.

TILLAGE

Tillage in dryland farming often provides benefits for crop production, but tillage also can be detrimental to long-term soil productivity and sustainability. Benefits of tillage include preparing a seedbed for planting, controlling weeds, and incorporating fertilizers, pesticides, and excess crop residues lying on the soil surface. With some soils, producers till to break up compacted layers in the soil and improve precipitation infiltration, or to construct ridges or bunds (mini-catchments) that increase water capture. Producers in the Euro-Asian Steppe, for example, till to form ridges perpendicular to the slope; this practice reduces runoff from snowmelt in the spring. Even with heavy residue cover on the soil surface, runoff is often greater in no-till systems than with tilled systems that include ridges.

Tillage is detrimental because it buries crop residues, thereby increasing soil water evaporation and soil erosion. Tillage also increases degradation of soil organic matter, thus gradually decreasing soil fertility as well as accelerating deterioration of soil structure. Tillage can cause soil compaction, especially if soil is wet during tillage. Even though tillage controls weeds that are present, tillage also lengthens survival of weed seeds by burying them in soil, thus increasing weed density in future years.

In many regions of the world, reducing tillage to preserve crop residues on the soil surface favors crop productivity. Yet, in situations where soils are poor in structure and fertility, such as in areas of Africa, tillage may improve crop production, at least in the short term. Also, in some regions the economic infrastructure may not provide producers with herbicides to replace tillage for weed control, thus tillage may be the primary option to control weeds.

Producers can compensate somewhat for the detrimental impact of tillage with cultural choices. For example, rotations comprised of crops with different life cycles can minimize impact of tillage on long-term weed dynamics and weed seed survival in soil. Diversity in crops helps producers manage weeds, thus reducing the need for tillage for weed control (see Anderson et al., 2006, this publication for more explanation). Because tillage is still a key component of production systems, we suggest that long-term studies are needed to assess impact of tillage on dryland crop production and soil sustainability.

EROSION

Land degradation and soil erosion are two of the most pervasive problems challenging sustainable dryland agriculture. Yet, in some regions, dryland farmers

have few affordable management options to address these problems. For example, wind erosion is prevalent where soils are loose, dry, and bare for much of the year, such as in western Texas or West Africa, but climatic limitations restrict protective cropping strategies. Soil degradation and erosion is now viewed as a more critical problem in Sub-Saharan Africa than drought and climate variability.

Management practices that degrade land quality include residue removal, continuous cropping with limited inputs, overgrazing, and cultivating soils that are marginal for crop production. One example of soil degradation occurs in southern Asia where crop residues are used for fuel or fodder; this practice accelerates loss of soil C and increases soil erosion. Producers in this region need cropping systems that produce fodder for feed and fuel without causing soil deterioration and reduced C levels. Erosion also reduces soil fertility by physically removing nutrients and organic matter from the land. Degraded soil also is less favorable for water infiltration, thus leading to a downward spiral of reduced crop productivity and soil sustainability.

Management practices that contribute to soil degradation throughout the world are often similar. For example, agricultural development of southern South America began with the "Conquista del Desierto" in 1879, which displaced indigenous inhabitants and introduced more intense agriculture production systems. The production of cereal crops using moldboard plow tillage led to extensive erosion during droughts of the early 1930s, similarly to the North American Great Plains and its soil erosion during the "Dust Bowl" years. A similar trend with moldboard plowing occurred in both Kazakhstan and the USA. The massive disruption of soil structure by the plow led both countries to encourage producers to replace plowing with conservation tillage.

Worldwide, numerous management practices are available for control of soil erosion. However, resource-poor farmers are often economically constrained in their choice of management tactics, as they often cannot afford the initial cost related to various control practices. The choice of management practices will depend on labor constraints, the economic environment, and soil type. But, most resource-poor subsistence farmers are not likely to undertake large soil and water conservation measures, such as building terraces or bunds, without aid from a government or international agency. No-till systems have not been widely adopted in many cases because of implementation costs.

NUTRIENTS AND SOIL ORGANIC MATTER RELATIONSHIPS

System productivity and sustainability are inextricably linked with soil fertility and soil organic matter content. Soil organic matter not only stores nutrients, but also affects soil aggregate stability and water capture in soil. Low soil fertility leads to low productivity, which results in less carbon (C) input to the soil, and eventually less water capture. Land degradation in developing nations occurs because of residue removal, continuous cropping with little or no inputs, or overgrazing, leading to a downward spiral of decreasing vegetative cover, increasing erosion, declining soil fertility, and declining yields due to nutrient exhaustion.

The worldwide pattern of soil fertility and organic matter decline must be reversed if global sustainability is to be realized. When soil cultivation begins in

dryland farming regions, it is usually on a low intensity level where few inputs are made other than seed and labor. As population increases, demand for food and forage increases and, as a result, cropping intensification increases. More intensive crop production results in more rapid exhaustion of soil nutrients; eventually deficiency of one or more nutrients occurs, usually nitrogen (N), and overall system productivity decreases. Unless nutrients are added as mineral fertilizer or biologically-fixed N, farming systems decline in overall productivity. With time, system productivity becomes uneconomical and farming is not viable.

In cases where indigenous soil nutrient and organic matter reserves are high, such as in native grasslands of temperate regions, it may be many years before system productivity decreases. Where original nutrient and organic matter levels are relatively low, such as in much of Africa, system productivity declines much more rapidly and the population can be plunged into poverty. Soil nutrient removal and subsequent deficiency is further exacerbated by competition for residues as animal feed and other domestic uses. Farmers in these situations have no means of replenishing soil nutrients because fertilizers either are not available or are too expensive to purchase.

Also, soil organic matter management can vary drastically among regions of the world. For example, producers in dryland regions of China often have too much crop residues; this contrasts with crop residue deficits commonly found with cropping systems in India and most African nations. To manage residues in China, producers usually burn their fields, but this tactic eliminates valuable C input to soils as well as leads to smoke pollution. Thus, different management tactics are needed to preserve organic matter and crop residues in these contrasting production systems.

Compared with developing countries, soil fertility and organic matter management appear to be a lower research priority on developed continents, such as Australia, Europe, and North America. Use of diverse rotations, proper nutrient management, and pest management has resulted in profitable and sustainable systems in these regions. In fact, some producers store soil C and receive C-offset credits with reduced-till practices. Researchers are conducting long-term studies to determine which cropping systems are most effective in C storage.

To address soil organic matter and fertility problems, researchers should focus on a holistic, system-oriented approach. A systems approach requires technology as common as soil testing, which is still missing in some countries. Even in cases where soil testing is used, there often has been a lack of soil test calibration research to legitimize the soil nutrient tests. Another global concern is that cropping systems that increase soil C inputs and C storage often require greater use of N fertilizers. This can increase nitrous oxide emissions, which trap heat in the atmosphere and favor global climatic changes. There is a research need to determine if the need for N fertilizer can be moderated by use of green manure or N-fixing crops.

NEED FOR SYSTEMS-BASED RESEARCH

We suggest that research for sustainable crop production under dryland conditions requires knowledge of numerous physical and biological processes.

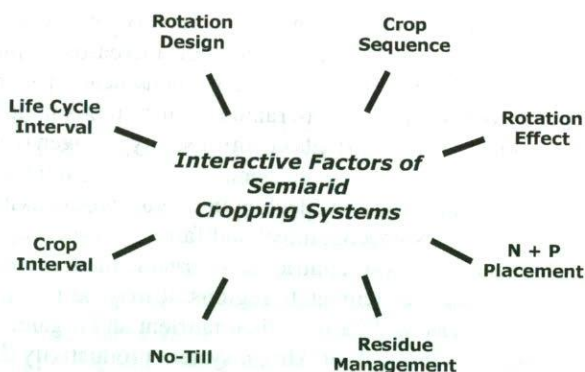


Fig. 22-1. Interactive factors involved in designing cropping systems in the semiarid Great Plains of the USA. Compared with winter wheat-fallow, diversified cropping systems are four times more profitable due to increased yields as well as reduced input costs.

These include organic nutrient dynamics, synchronization of nutrient mineralization with plant demand, and C cycling in the soil-biomass-atmosphere system. With the complexity of problems present in dryland agriculture as well as these interactive biophysical processes, producers may need solutions that transcend a specific discipline or research specialty and require farmer participation in research planning.

To illustrate this concept, we describe an example from the Central Great Plains of the USA where numerous benefits resulted from developing a diversified cropping system (Fig. 22-1). The prevalent cropping system in this semiarid region is winter wheat-fallow; with no-till systems, producers are including summer annual crops such as corn or sunflower in this rotation. These crops are now successful because of improved water relations resulting from crop residues remaining on the soil surface (Farahani et al., 1998).

The first benefit producers noted with diversified rotations and no-till was that weed density was considerably lower than expected (Anderson 2003). This trend reflects the interaction of weed demographics with tillage and crop sequencing; tillage buries weed seeds and increases their survival over time compared with no-till. Consequently, more weed seedlings emerge in tilled soils. Also, crop residues on the soil surface reduce establishment of weed seedlings in no-till. Weed control is further improved because these rotations included both cool- and warm- season crops. Different planting dates among these crops provide more opportunities to control weeds during a rotation cycle. Another benefit of diversified rotations is that plant diseases, especially with sunflower, are less detrimental. An effective sequence for both weed and disease management is arranging crops in a cycle of four, with 2-yr intervals of cool-season crops followed by warm-season crops.

Producers also noted that crops use water, N, and phosphorus (P) more efficiently if fallow is not included in the rotation. (Anderson 2005). Producers further enhance nutrient-use efficiency by placing N and P fertilizer by the crop row.

Compared with winter wheat-fallow, diversified cropping systems increase net economic returns fourfold (The National Center for Food and Agricultural Policy, 2004). Higher returns reflect not only more crop yield, but also less input costs due to fewer pests and more efficient use of nutrients. A further benefit is that producers are improving soil physical, chemical, and biological properties. For example, with winter wheat-fallow, organic matter levels were continuously declining; with diversified cropping systems and no-till, organic matter levels are increasing (Bowman et al., 1999).

Because of these benefits, cropping practices in the region are rapidly changing. During the 1980s, winter wheat comprised 95% of dryland crops; in 2000, corn, sunflower (*Helianthus annuus* L.), proso millet (*Panicum miliaceum* L.), and other alternative crops occupied almost 50% of the cropped land area. Our example illustrates how a systems approach can provide alternative solutions to problems faced by dryland farmers.

Finally, although we have focused on the major research needs identified by authors from different parts of the world, we also realize that a complex set of socioeconomic factors affect dryland crop production. Such factors include land and water resources, population pressures, income disparity, land tenure, government policies, traditions, religion, family structure, markets (ranging from local to international), economics of implementing conservation practices, and emphasis on environmental issues. Based on the wide array of agro-ecological and socioeconomic factors involved, agriculture under dryland conditions certainly is an extremely challenging and risky enterprise.

REFERENCES

- Anderson, R.L. 2003. An ecological approach to strengthen weed management in the semiarid Great Plains. *Adv. Agron.* 80:33–62.
- Anderson, R.L. 2005. Improving sustainability of cropping systems in the Central Great Plains. *J. Sustain. Agric.* 26:97–114.
- Anderson, R.L., K.L. Bailey, and F.B. Peairs. 2006. Guidelines for integrating ecological principles of pest management with rotation design. p. 195–226. *In* G.A. Peterson et al. (ed.) *Dryland agriculture*. 2nd ed. *Agron. Monogr.* 23. ASA, CSSA, and SSSA, Madison, WI.
- Bowman, R.A., M.F. Vigil, D.C. Nielsen, and R.L. Anderson. 1999. Soil organic matter changes in intensively cropped dryland systems. *Soil Sci. Soc. Am. J.* 63:186–191.
- Farahani, H.J., G.A. Peterson, and D.G. Westfall. 1998. Dryland cropping intensification: A fundamental solution to efficient use of precipitation. *Adv. Agron.* 64:197–223.
- The National Center for Food and Agricultural Policy. 2004. Representative farms economic outlook for the January FAPRI/AFPC Baseline. Available at <http://www.ncfap.org/> (verified 9 Jan. 2006).